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APPLICATION OF ADVANCED ANALYSIS METHODS TO THE LIFE CYCLE MANAGEMENT OF SHIP
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Application of Advanced Analysis Methods to the Life Cycle Management of Ship Structures

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Abstract

In the process of initiating more efficient maintenance practices for the new Halifax Class frigates, the requirement for an effective means to assess operational structural integrity arose. This paper describes the general plan for a five year development project entitled 'Improved Ship Structural Maintenance Management' - ISSMM, begun in 1996 with the goal of producing a tool which will use modern methods of analysis to efficiently assess the operational capability of the Halifax Class structure in an intact, degraded or damaged condition. The overall philosophy and general approach to the development of sea load models, structural analysis methods for fatigue and strength, damage modelling, the assessment of residual strength and risk of operation, and verification through component testing and sea trials are discussed.

Introduction

The Canadian Forces (CF) have initiated improvements to maintenance practice for naval vessels through a program entitled the Naval Ship Maintenance Program (NSMP) which encompasses new survey and repair procedures and guidelines, a computer database to track inspection and repair actions (Structural Inspection Database - SID [1]), and a process for certifying the structural integrity of each vessel (Ship Structural Integrity Program - SSIP). This program is being implemented to address maintenance of the new Halifax Class frigates, which will be the backbone of the fleet for the next 30 years. Inherent in this overall program is the need to determine the structural capability of the vessel in its current condition to meet its operational requirements. To meet this need, DND initiated a major development project, ISSMM (Improved Ship Structural Maintenance Management), to develop an integrated computer-based approach using modern methods of analysis to efficiently assess the structural integrity of CF vessels in a damaged or degraded condition. The ISSMM project was initiated in April 1996 after a three year concept planning period [2] and is due to complete in March 2001.

Traditional ship structural design methods do not lend themselves to determination of the operational structural integrity of an in-service vessel in a degraded condition. Recent advances in structural analysis technology such as the finite element method, improvements in the ability to model realistic sea loads, development of fatigue and fracture mechanics methods, and the rapid advancements in computing technology, make it possible to develop methods to

evaluate the structural capability of a vessel, including the effects of degradation, against the requirements of its mission. A major goal of the ISSMM project is to make this technology accessible to the CF engineering community.

Efforts with some similarities to ISSMM have been initiated by other agencies involved in ship structures throughout the world. Most of the major ship classification societies are developing design methods for commercial vessels based on more realistic methods of modelling sea loads and finite element methods of structural analysis. These programs are primarily directed at ship design rather than detail analysis of existing structures, and do not address naval vessels or the effects of degradation.

This paper describes the general philosophy and approach to the ISSMM project including the development of an extensive structural database for the Halifax Class, prediction of realistic sea loads for specific short and long term operations, modelling of damage, implementation of structural analysis methods to determine ultimate hull girder and component strength, development of methods for fatigue crack initiation and growth analysis, methods of assessing residual strength and operational risk, and verification of the methods through structural component testing and sea trials.

Application of ISSMM

It is not uncommon in the operation of ship structures to unexpectedly discover or incur significant structural damage in the form of corrosion, cracking or deformations which can potentially have consequences on the immediate operational requirements of the vessel. The naval engineer is often faced with having to provide recommendations on very complex structural problems in a short period of time. The goal of the ISSMM project is to provide the engineer with an effective and efficient tool to aid in making structural operational capability decisions. Given a description of the damage and the mission operational profile, ISSMM will help the engineer make an assessment of the change in structural capability of the vessel. This will improve his ability to make rational, timely recommendations for restricted operations and short and long term maintenance actions.

User input to the program will be a description of the damage and the mission operational profile. An extensive database for the Halifax Class will contain structure, materials and load data, including finite element models, generic damage models and load sets for predefined operations. ISSMM will use this information to assess fatigue, hull girder strength and component strength. A flow chart of the different modules of the ISSMM program is given in Figure 1.

ISSMM Database

One of the main advantages to be realized in creating a special purpose comprehensive analysis tool such as ISSMM, is that it can readily contain most, if not all, of the required load and structural data for analysis of the various failure limit states. The most time consuming task in current ship structural analysis is acquiring and implementing the necessary data. Often an analysis is limited by what data is available and what can be put into the necessary format in the time

allotted. The database will contain all information necessary for the various modules of ISSMM: weight distribution and lines plans for the seakeeping (loads) analysis; world wide wave statistics, results for the Halifax Class of the linear 3-D sea loads analysis, predefined operational profiles including global structural responses, the basic hull girder structure finite element model and detail finite element meshes of critical structure; materials data including information for nonlinear behaviour and fatigue crack initiation and growth; and, second order (means, COV and distributions) statistics of the structural parameters for reliability analysis. Accurate weight distributions are being developed for the Halifax Class with consistency between the sea loads and structural models.

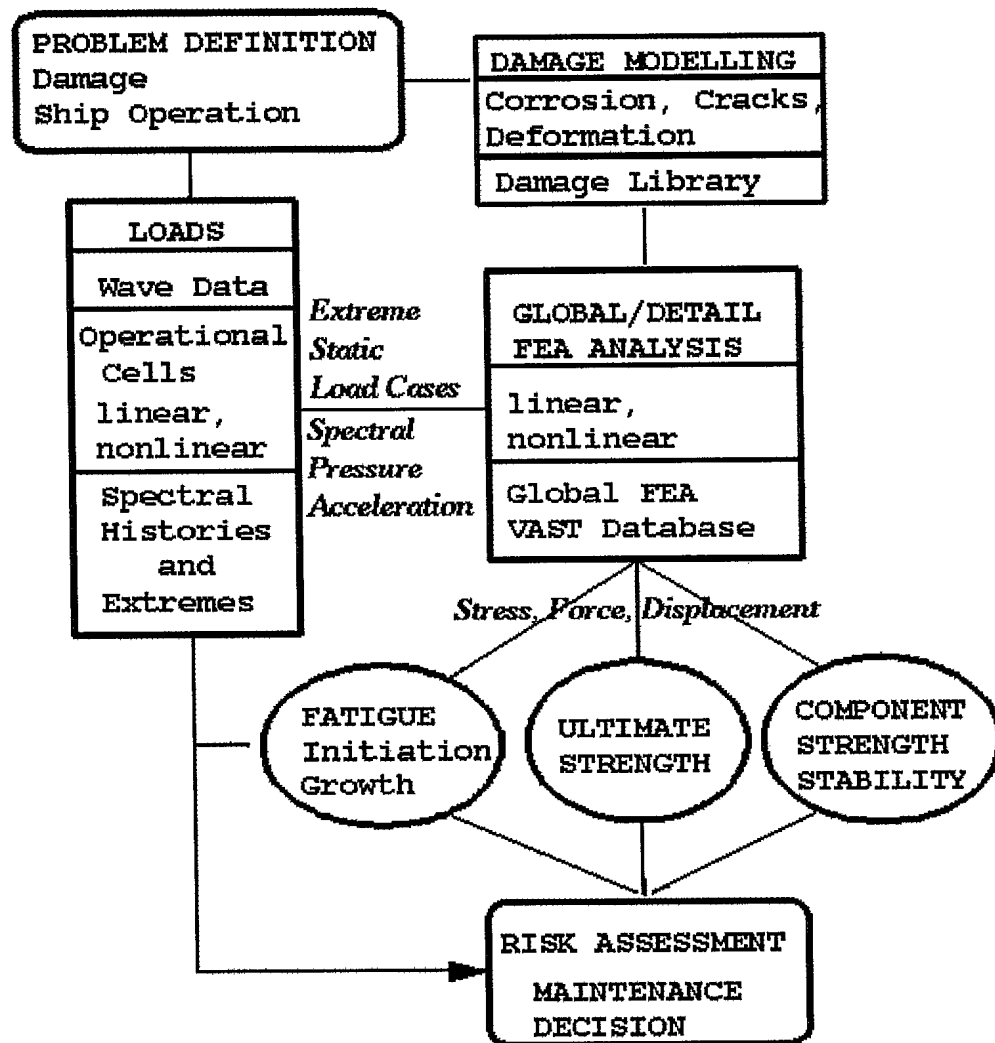


Figure 1: Flowchart of the ISSMM Analysis Modules

Material properties for Halifax Class steels are being generated through a materials testing program. Tensile yield, strength and hardening characteristics for the A517 and 350WT base metals and three weld metals are being generated and stored in the database. Fatigue crack initiation and propagation constants in-air

and in-seawater are being developed for the two steels, as well as fracture toughness characteristics for fracture analysis.

Work is underway in developing a hierarchical object oriented database (HOOD) system for ISSMM. Advantages of this approach are ease and speed of access from computer codes, storage space efficiency, and ease of future modifications. By using the class structure of C++ programming, the HOOD system will allow an efficient relational transfer of data between the various modules of ISSMM. For example, a finite element or a group of finite elements used to model a segment of longitudinal between two frames in 01 deck would have a hierarchical labelling process defined as:

```
{Halifax Class...
    {deck01...
        {grillage-p-45-55...
            {stiffenedpanel-f47,48-L9,10...
                {long-9
                    {material, elements}}..}..}..}
```

This database system would allow easy identification of the elements and materials used to model longitudinal number 9 which is part of the stiffened panel component bordered by frames 47 and 48 and longitudinals 9 and 10. The stiffened panel component is part of a larger grillage structure on the port side between frames 45 and 55 which is part of the 01 deck of the Halifax Class. This approach to database development will allow the derivation of the loads and scantlings of longitudinal 9 for component strength and stability assessment through equation-based limit states or more comprehensive local finite element analysis. The stiffened panel level will allow the derivation and/or storage of the information necessary to develop structural unit load shortening curves for ultimate strength assessment. The higher level structural definitions will allow strength assessment of grillages, logical boundaries for top-down finite element analysis and reference to libraries of other meshes of these areas which may exist.

Creation of this database will require a significant effort, but since it is being done in advance for a specific existing ship, this effort is more than justified in the benefits gained in efficiency of future analysis requirements. Model generators to create this database are being developed with the initial definition levels being created by modifying and augmenting global structural information in an existing MAESTRO [3] model of the Halifax Class.

Structural Sea Loads

The user of ISSMM will enter the expected vessel operation which will be used to estimate the extreme load and the cumulative load history for the structural assessment. Two methods of entry for the operational profile will be developed. A 'user defined' option will allow the user to map out a ship route and define probable headings and speeds. Alternatively, the database will contain a 'canned' set of long and short term operational profiles which are being developed based on current and expected CF ship deployment practice. In addition, a set of profiles

based on increasing severity of sea state will be generated for the database. These profiles would model the ship transiting a fixed sea state or a severe storm, thus allowing for the operator to determine the risk of operating in various sea conditions.

Ship response transfer functions (RAOs for accelerations and pressures) for regular waves at a specified period, ship speed and heading to the waves, and ship displacement will be determined through three-dimensional linear seakeeping analysis methods. Ship operational profiles will be described in terms of the time spent in various operational cells which are a function of significant wave height, wave period, ship speed, heading to waves and ship displacement. Ocean wave statistics are available through world wave statistics databases such as that supplied by BMT [4]. Wave spectra will be described by the Bretschneider two-parameter spectrum. For each operational cell, load data will be developed initially from the RAOs with the addition of nonlinear and transient load components as these become available. The operational cells will contain the following data for each of 5 headings (head, bow, beam, quartering, and following seas), 5 speeds (5, 10, 15, 20, and 25 knots), 9 significant wave heights (1, 4, 6, 8, 10, 12, 14, 16, and 18 m), and 15 modal wave periods:

- RMS values for hog and sag vertical bending moments (VBM), lateral bending moment (LBM), and combined vertical and lateral bending moment (BM),
 - RMS rigid body accelerations,
 - RMS shear forces,
 - still water bending moment (SWBM),
 - associated upcrossing periods,
 - cross correlations between all load effect components,
- for 10 ship sections along the length of the ship, and
- hull panel pressure transfer functions (RAOs) for a 3-D panel model.

This may also have to be done for more than one ship displacement if it is deemed necessary. In the case of linear load analysis, the data for the higher significant wave heights are obtained by simply scaling the 1 metre data.

Translating the dynamic, multi-valued sea loads occurring on a ship structure, as a result of defined operations in a seaway, to static or quasi-static structural load cases proved to be a challenging aspect in developing the detailed plan for ISSMM. Advances in both sea loads predictions through more advanced frequency and time domain codes, and structural analysis using finite element analysis and failure modelling, need to be matched by development of suitable interfaces between the loads and structural analysis. The methods of structural load case development for ISSMM build on current technology such as the American Bureau of Shipping (ABS) Dynamic Load Approach (DLA) [5] approach and the coupling of finite element analysis with three dimensional sealoading codes developed through DREA (Figure 2).

Three categories of ship hull structural failure will be addressed by ISSMM. They each require a specific load case or cases.

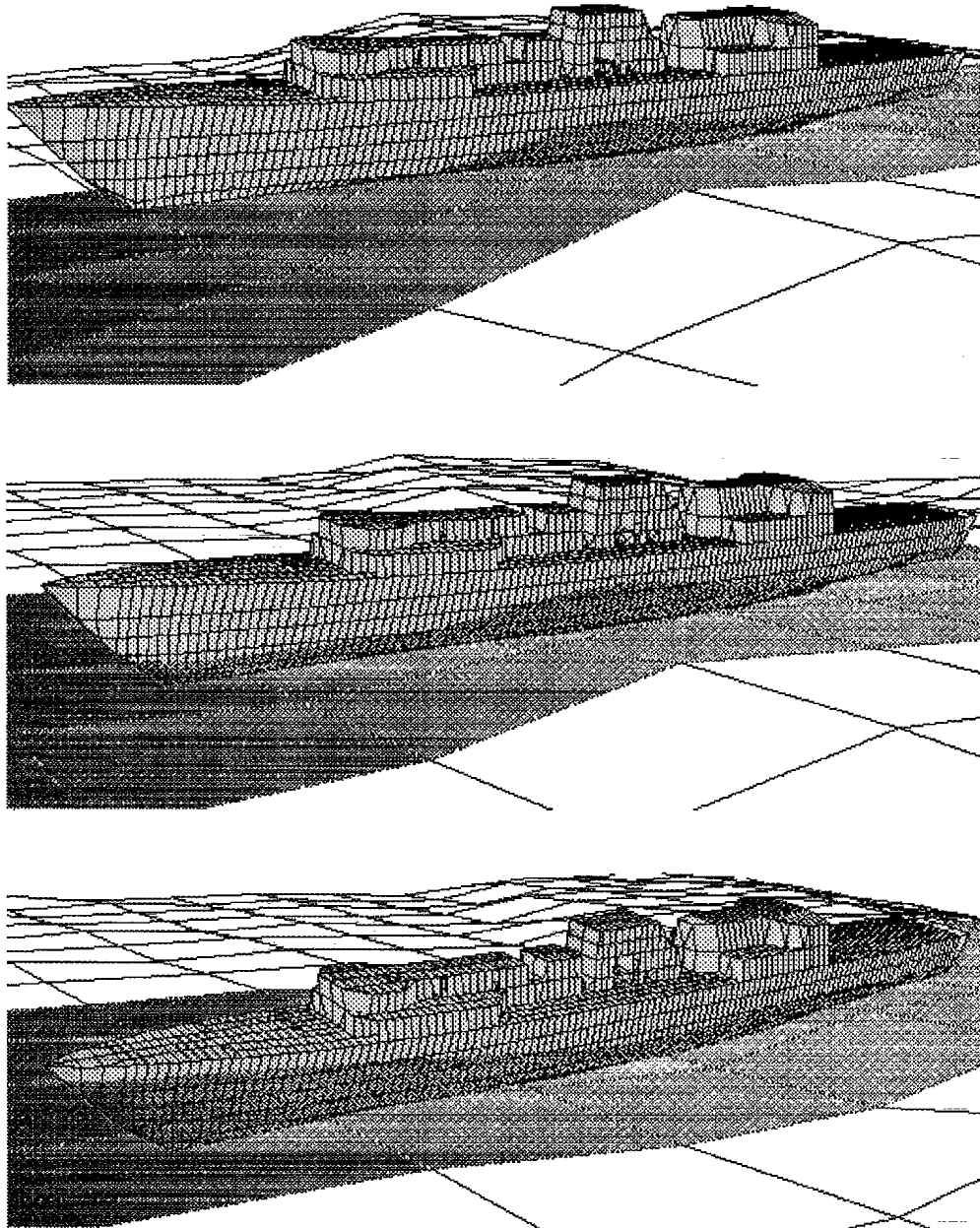


Figure 2: Representation of a Full Ship FEA Model in an Irregular 3-D Seaway for Load Calculations

1) Hull Girder Ultimate Strength Loads

The hull girder ultimate bending limit state requires an estimate of the extreme bending moment that is likely to occur in a given operational profile. The extreme value may occur in the vertical plane (VBM), the lateral plane (LBM) or in some plane comprising a combination of VBM and LBM and will be derived from operational cell data using extremal theory. A facility to include slamming and green seas effects on the extreme VBM will also be investigated.

2) Component Failure Loads

A component may consist of a single plate panel, connection or a larger section of orthogonally stiffened grillage. The maximum force exerted on a component from the combination of hull pressure and acceleration load effects is required to evaluate component strength and stability. A modification of the ABS DLA approach to include nonlinear loads and to be more specific for naval frigates is being investigated. The basic premise of the DLA approach is that the extreme component load occurs in the same physical load situation (operational cell) as does the maximum dominant load effect occurring in all of the individual operational cells that contribute to the total mission. It should be noted that the term 'maximum' refers to the largest statistical value occurring in the individual operational load cells, and that the term 'extreme' refers to the statistically extrapolated single event value over the entire mission operational profile.

The extreme value of the dominant load parameter and the identified operational cell physical loading condition, are used to derive an equivalent extreme significant regular wave static load case, consisting of accelerations, pressures and end moments and shears for the global hull structural model. Nonlinear seakeeping theory will be used to develop the extreme loads. The three-dimensional finite element frequency response analysis method described below for fatigue, will allow the determination of maximum stresses or forces anywhere in the global finite element model as a function of the operational cells and may provide an alternative means to determine the dominant load parameter for identifying the extreme operational load cell.

3) Fatigue Loads

Fatigue analysis includes both crack initiation and crack propagation. Crack initiation requires the strain or stress history at the specific point where the crack is expected to start. This will usually be at the point of highest strain. Crack growth requires the strain or stress history over a region of structure where the crack will likely propagate in addition to the stress intensity at the crack tip. Both of these types of fatigue calculations will be implemented into the FE based code, LIFE3D [6] for ISSMM.

There are several possible approaches to developing the stress cycle load information for fatigue analysis. Methods based on deriving VBM exceedance curves from operational cells as described by Sikora et al. [7] are most common. These can be extended to combine VBM and LBM effects in the operational cells to get a histogram of stress or stress intensity which can be divided into smaller units to undertake crack growth analysis. A more comprehensive approach is to use a quasi-static spectral finite element structural analysis with pressure and acceleration frequency response functions as input to derive stress and stress intensity spectra.

The initial phase of ISSMM is developing and investigating the feasibility of this latter method described as follows. For each regular wave operational cell, the complex components of pressure for each discrete panel on the hull hydrodynamic model, and rigid body accelerations will be calculated using the linear three-

dimensional sea load code, PRECAL [8]. These complex pressure and acceleration data (per regular wave condition) are then converted to a complex finite element global force vector which is used with the finite element method to calculate complex nodal displacements. These global values of the regular wave load effects will be calculated once and stored for the global Halifax Class model. Complex stress or stress intensity spectra are then calculated for each operational cell from global displacement (or force) boundary conditions in a top-down finite element analysis. The cell stress spectra are then combined into a mission operation spectrum. This method cannot directly include load sequencing and crack retardation effects. Different methods of ordering of the spectra are being investigated including a mean distribution and upper and lower bounds.

4) Still Water Loads

All of the structural failure modes are affected by the forces induced by the still water condition of the ship. Destroyers and frigates, unlike supply ships and commercial cargo vessels, do not have significant changes in weight during operations or even during life, with the exception of major refits where equipment may be changed. It is therefore proposed that only the deep departure weight condition be used for ISSMM. A limited investigation of the differences in some load effects between the light ship and deep departure condition will be undertaken to ensure that this assumption will not lead to unconservative or overly conservative load assessments. The still water load and resulting load effects in the global finite element model will be stored in the Halifax Class ISSMM database.

Description and Modelling of Damage

Once the user has defined the vessels operational profile, which may be as simple as choosing a 'canned' operation, it will then be necessary to define and model the damage or degradation. The assessment of the effects of damage will be done as a comparison of the damaged case against the undamaged case for the given operation. Damage will be incorporated into the structural models and evaluated against the fatigue, ultimate strength and component failure modes. The types of damage to be considered in ISSMM will be:

Cracks: propagation of detected cracks will be investigated as well as the crack's effect on ultimate strength and component failures through loss of structural continuity.

Corrosion: the effect of loss of cross sectional area on component strength and stability and on the hull girder ultimate strength will be investigated. Corroded areas which result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation.

Deformation (Dents): the effect of geometric deformations on component failure will be investigated. Subsequent changes in component load-shortening curves will be considered in terms of hull girder ultimate strength. Deformations which result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation.

Loss of Structure: Damage cases (possibly weapons or severe collisions) which result in loss of part of the structure will be modelled by removing components of the structural models. The effect of loss of structure on ultimate strength and on load redistribution for component strength will be evaluated. Structural discontinuities which may result in high stress concentrations will be investigated for possible crack initiation and subsequent propagation during the operation. The occurrence of damage can also induce significant plasticity and residual stresses in the surrounding structure.

A number of possible damage scenarios were discussed during the planning of ISSMM. This will be an ongoing process in the development and testing of ISSMM. Two such examples are:

- A .3 m crack has been found emanating from an opening in 1 deck. Should it be repaired now or can it be left and if so, for how long? ISSMM Application: Assess the fatigue crack growth rate over the expected operation of the vessel. The goal will be to determine if the crack has any reasonable chance of reaching its critical crack length. The effect of the crack on the load-shortening curves and ultimate strength analysis as the crack grows will be evaluated.
- A 6m x 3m area of corrosion has been found in a midship tank. Can the frigate escort a convoy from Halifax to the U.K. (and return) during the autumn? ISSMM Application: A means to develop models of corrosion damage given surveyor information will be developed. The main concern in this scenario is the component failure of the affected plates and their adjacent structural components and the effects on hull girder ultimate strength behaviour.

Damage will be modelled by altering the detailed finite element meshes of local structure. This is not a straight forward process with conflicting objectives of minimal user input (not requiring the user to be an expert in finite element analysis) and creating models which correctly represent the effect of the damage on the ship's structural integrity. This will require a predefined set of generic damage models from which the user will select the one most closely resembling the true case. Semi-automated finite element modellers will be developed to represent estimates of reported ship damage. A general purpose finite element modeller to create the damaged structure will also be available in ISSMM.

A library of generic damage models will be created such as: crack detail models of cracks emanating from the side of circular cutouts or occurring along butt-weld lines; models reflecting depth and patterns of corrosion measurements on plates; models which allow specific deformations from measurements or general patterns and amplitudes of deformation; and a means to remove structure from models. The ISSMM user will select the generic model that best represents the problem of interest and embed it in the finite element model of the structural area of interest.

Structural Analysis

Once the user has defined the damage and the operational profile for the vessel, the structural analysis module of ISSMM will provide the means to translate loads to

load effects in the intact or damaged ship structure. These load effects are the moments, stress, strain, displacement, and forces which will be passed on to the ultimate strength, component strength and stability, and fatigue evaluation modules. Linear and nonlinear FEA with the DND code VAST [9] will be the main method of structural analysis used.

The structural analysis will be based on a global coarse mesh model of the entire ship combined with fine mesh models of specific areas of interest. Models of intact or damaged structural details will be developed from the database of existing detail finite element models which will include the main strength deck, longitudinal bulkheads and primary bottom structure, or be created from structural drawings or existing electronic data files of structural layouts. The fine mesh model will be incorporated into the coarse mesh model by either a top-down approach where displacement or force boundary conditions are derived from the global coarse mesh model and applied to a separate detail finite element model, or a bottom-up analysis which imbeds the detail model into the global model followed by solving the full combined stiffness matrix. These capabilities exist in a basic form now in the MAESTRO/VAST Detail Stress Analysis (DSA) program initiated by DREA and Martec Ltd of Halifax in 1994 to facilitate the detail stress analysis of ship structural components within a full global finite element model of the hull. Stress at structural details for fatigue analysis, and the distribution of forces and displacements to study structural component strength and stability in response to a given load will be provided by the DSA engine. Figure 3 shows a detail model of the midship main deck and longitudinal bulkhead structure as it would be imbedded into a VAST global model of the Halifax Class hull and superstructure.

The VAST-DSA capabilities are being updated to include nonlinear large displacement elasto-plastic static collapse analysis for stiffened panels using an automated system of 'smart' modelling and nonlinear analysis procedures. VAST is also being used to produce the crack tip stress intensity values from fracture mechanics finite elements for the crack growth models. A set of graphics tools is being developed in C++ and Open GL to provide the visualization of models and results of analyses.

Ultimate Strength Assessment

ISSMM will investigate effects of damage on the maximum bending moment resistance of the ship hull girder cross sections in the vicinity of the damage and in the midship region. ISSMM will use the approximate two-dimensional ISUM (integrated structural unit method) approach that has been incorporated into the codes ULTMAT [10] and FABSTRAN/NS94A [11] currently used for hull girder ultimate strength calculations in DND. The elasto-plastic axial deformation characteristics (load-shortening curve) of individual stiffened plate units which make up the cross section of interest are required for these programs. The load-shortening curves can be generated from nonlinear finite element analysis or other numerical approaches and test data.

Bending moments resulting from other than a head (or following) sea direction and unsymmetric hull girder structure, such as may result from damage, will cause unsymmetric biaxial bending about a neutral axis other than one of the principle axes (vertical or horizontal axes) of the ship. Ultimate hull girder failure under

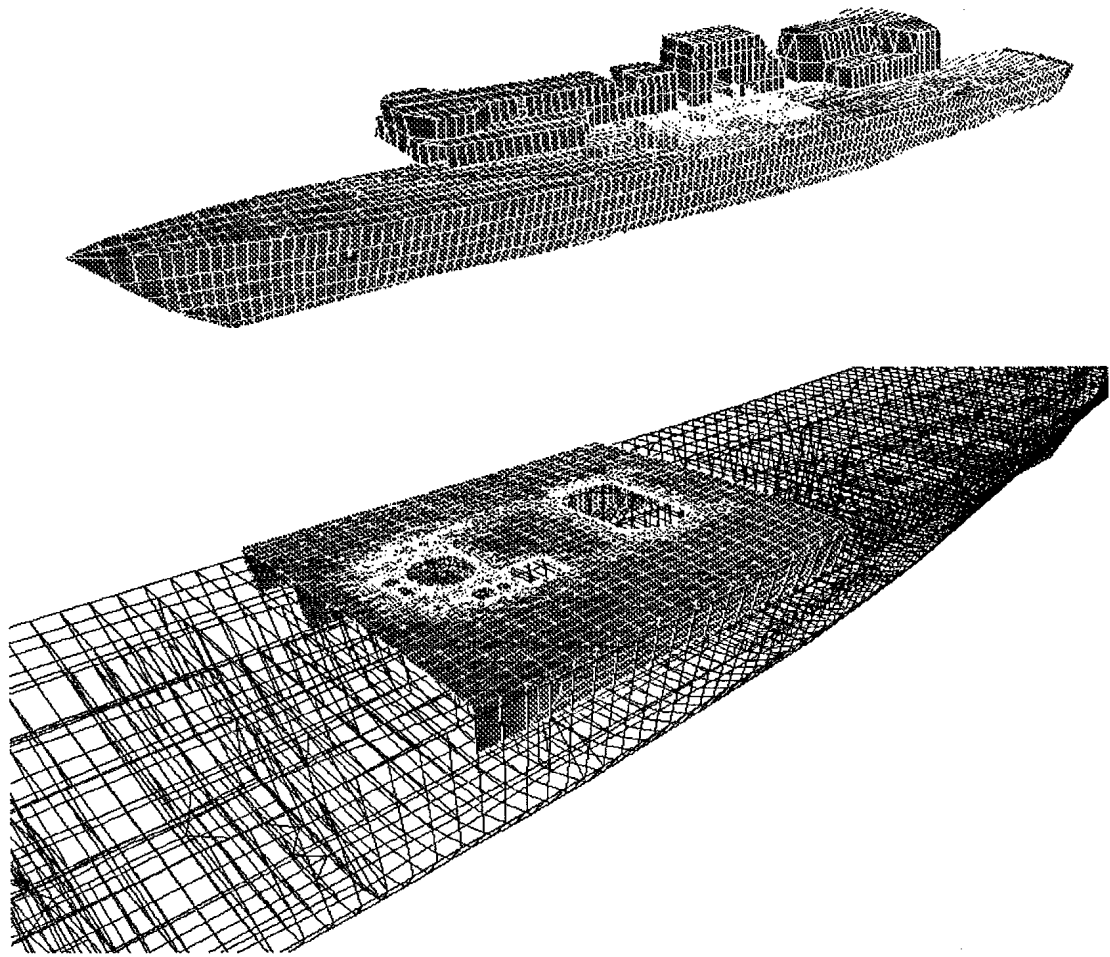


Figure 3: Detail Midship Deck Finite Element Model as it would be Imbedded Into a Global FE Model of the Halifax Class

biaxial bending can be determined by using an interaction diagram between lateral and vertical ultimate moment capacities. This will be investigated for ISSMM and compared to results using only vertical bending moment.

For the intact Halifax Class structure, load-shortening curves of stiffened panels will be generated for several sections of the hull girder and stored in the Halifax Class database for access by the ultimate strength analysis code. Many of these curves exist already for the Halifax Class from previous work. The proposed method to investigate the effects of degradation or damage on ultimate strength is to determine the change to the unit load-shortening curves caused by the damage and to incorporate the new unit load-shortening curve in the section ultimate strength calculation. In the worst case, the unit would be completely removed from the analysis indicating that that part of the structure cannot take any load. Alternatively, nonlinear finite element analysis will be used to create new load-shortening curves for the damaged panels.

The risk of ultimate strength failure will be assessed by comparing the intact and damaged ultimate strength resistance to the expected extreme bending moment for the intended operation. Both a probabilistic assessment of failure and a deterministic change in safety factor will be determined.

Fatigue Assessment

ISSMM requires the assessment of fatigue cracks during ship operations. This will include both the probability of a crack initiating in an area of identified large stress concentration (possibly as a result of damage) and the probability of a detected crack propagating during a defined operation. Due to the considerable uncertainties associated with fatigue calculations, they are generally undertaken with considerable conservatism and the general philosophy of ISSMM will be to determine whether there is any reasonable likelihood that a crack will form and become critical during the intended operation. Monitoring and reporting crack growth progress during the ship operation will be an essential part of the ISSMM analysis. The approach proposed for ISSMM is quite progressive and an initial investigative phase is being undertaken before the method is fully integrated into the program.

The hot-spot approach to crack initiation using the Palmgren-Miner rule is being evaluated for implementation in ISSMM. Strain-life calculations using residual or residential strain states determined by X-ray diffraction mapping of the hull are being developed.

ISSMM will also incorporate models to predict the growth rate of an already existing fatigue crack. The crack growth rate depends on the stress state of the material which the crack itself influences, therefore an iterative solution scheme is necessary. Finite element models will be used to predict the stress intensity cycles at the crack tip and the stress field around the crack from the spectral analysis of the operational profile. Various crack growth laws are being investigated to determine which may be most appropriate.

Finite element modelling is the most suitable method to use to determine stress (or strain) and stress intensity values in ship structural details. The VAST-LIFE3D program uses a detail finite element model of the crack tip region including elements which calculate the stress intensity at the crack tip from the local stress field. Loading is applied to the detail finite element submodel from the global FE model. The crack tip stress intensity and the loading frequency are then used in a particular crack growth law to determine how far the crack will propagate. As the crack propagates, the detail mesh at the crack tip and its immediate surroundings is remeshed to reflect the change in geometry. In order to minimize the uncertainties associated with meshing, a semi-automated smart meshing approach is being developed for stress detail and crack tip meshes which are appropriate to the fatigue models being used. This proposed meshing capability in ISSMM is an ambitious undertaking but necessary to allow meaningful fatigue analysis in a general user program such as ISSMM. Figure 4 shows a VAST top-down model of a crack propagating from the edge of a circular cutout in a longitudinal bulkhead.

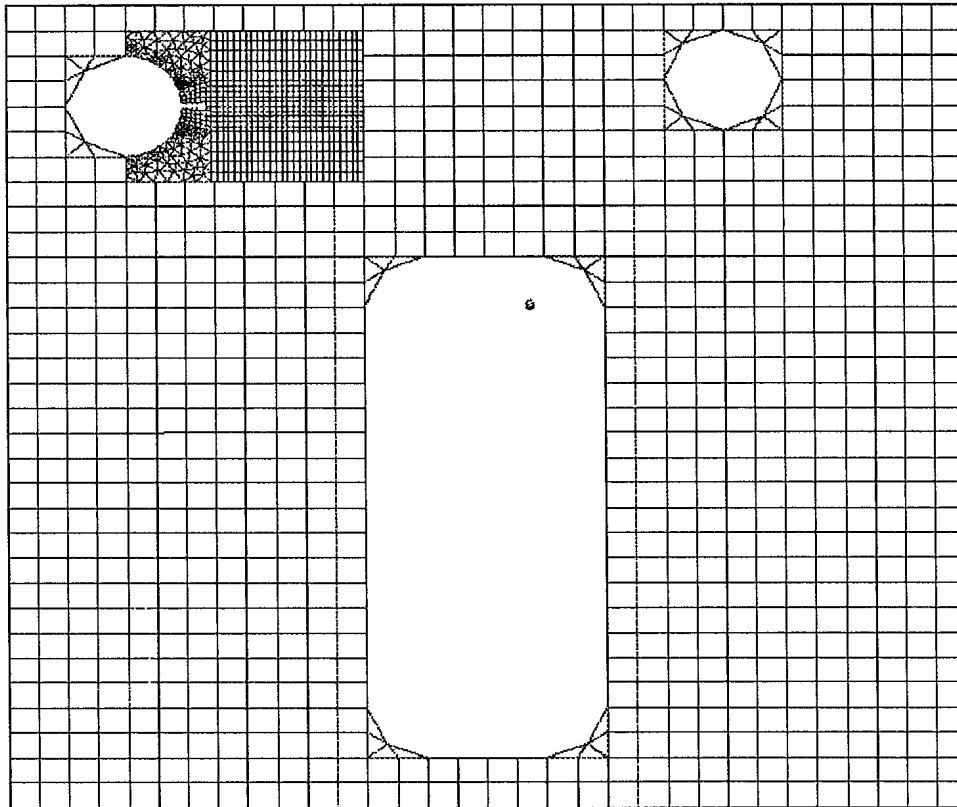


Figure 4: Semi-automated Top-Down Modelling Of Crack Propagation At A Bulkhead Circular Cutout

Component Strength and Stability

The third category of failure mechanisms addressed in ISSMM is the performance of individual ship structural components. The effects of damage will be to either change the configuration of the component itself, or to change the load which is applied to the component as a result of damage in adjacent components. Strength and stability are the structural parameters which must be evaluated for each component.

The ship structural components that need to be evaluated are:

- longitudinal beams between frames or bulkheads,
- longitudinal beams between major transverse structure,
- transverse beams between longitudinals,
- transverse beams between major longitudinal structure,
- single plate panels between longitudinals and transverse frames,
- single stiffened plate panels between frames,
- grillage systems consisting of orthogonally stiffened plating bordered by major transverse and longitudinal structure,
- transverse bulkheads,
- longitudinal bulkheads, and
- the above structure including cutouts and discontinuities.

Identification of the structural components and the forces which act on them will be done through the hierarchical finite element database of the Halifax Class structure.

The component strength may be determined by various methods. Simplified components such as simply supported beams and plate components will be evaluated against DND ship design standards which reflect the U.K. SSCP-23 standard[12]. More complex structure and/or load distributions will require a finite element analysis of the component.

Structural stability of components subject to in-plane and possibly lateral loading will be done in a simplified linear elastic equation-based approach (as above for strength) or a more complex finite element analysis. The nonlinear elasto-plastic buckling collapse loads of ship structural components is the same capability required for the development of unit load-shortening curves for ultimate strength.

The limit values of the components calculated by the code equations or finite element analysis will be compared to the extreme stresses and forces which the component will see during the intended operation. These will be derived from the extreme quasi-static load cases and finite element analysis. Probabilistic limit states will be used for the component evaluation as well as deterministic changes in safety factor.

Verification and Validation

Critical components of the ISSMM project which will ultimately determine its usefulness are verification and validation. Verification will ensure that all of the software modules run correctly and, validation that the analysis algorithms adopted represent an operating Halifax Class frigate.

A set of test problems will be developed to continually test and verify the operations of all software modules as they are developed throughout the course of the project. Contractors developing software algorithms will be asked to verify and demonstrate their codes against specific problems. Independent checks of all finite element models in the database will be undertaken. Solution time, which is an important issue for ISSMM, will be tracked throughout the development to ensure that any particular modules are not unduly slowing down the analysis.

Sea load predictions for the linear and nonlinear regimes will be validated against existing model test data such as the CPF hydroelastic model [13]. Other model scale and some full scale load results exist which will also be used for comparison. Sea trials similar to those described in [14] will be conducted to validate the loads and structural response algorithms used in ISSMM.

There are some data available for box girder bridges and panels [15], and a very small number of tests for ship structure sections [16]. Comparison of the ISSMM method for ultimate strength will be done against these tests and more sophisticated nonlinear finite element analysis. It will be necessary to prove the capability for damaged structure through limited component testing.

Test data for fatigue crack initiation and growth for problems of specific interest to ISSMM and naval vessels in general may be insufficient, and Canada is discussing

collaborative test programs with our naval allies. Crack propagation through complex structure such as eccentrically stiffened deck structure needs to be evaluated through testing.

A testing program similar to some already conducted [15] will be carried out to evaluate corrosion and deformation damage in Halifax Class stiffened panel structure.

Discussion and Conclusions

This paper has discussed the development plan for the DND major project ISSMM as it exists at this time. This plan is the result of continuing detailed discussion between many individuals involved in the project. The plan described in this report is felt to be progressive and very capable of meeting the needs of the CF in evaluating ship structural capability for effective hull maintenance management.

ISSMM relies very much on advanced computing power. Most of the methods being used in ISSMM have been available for some time, but it would not have been possible to rationally discuss a plan such as this a few years ago, as affordable computing technology would not have been adequate. ISSMM is also being developed in such a way that future advances in the various technologies such as sea loads, structural analysis, fatigue analysis, reliability theory and computer and data processing, can be easily adopted.

Acknowledgements

The production of the general development plan for ISSMM has involved detailed discussions with many individuals who are involved in the project. The authors acknowledge valuable contributions from Dr. Richard Morchat, the Project Director; Dr. Ross Graham, Layton Gilroy, Sam Ando and Dr. Kevin McTaggart on loads development; Dr. Thomas Hu on ultimate strength evaluation; John Porter and Dr. David Stredulinsky on material property aspects and fatigue analysis; David Heath on database management and graphics; Lt.(N) Heather Skaarup, LCdr Ken Holt and several other colleagues and contractors who have willingly expressed their ideas on the ISSMM project.

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